British Journal of Plastic Surgery (1980), 33, 371–376
0007-1226/80/0082-0371 $02.00

THE EFFECTS OF VARYING DEGREES OF TENSION ON THE VIABILITY OF SKIN FLAPS IN PIGS

By P. M. Stell, Ch.M., F.R.C.S.
Professor of Oto-Rhino-Laryngology, Royal Liverpool Hospital, Liverpool L69 3BX

Every surgeon knows that when he incises skin in most parts of the body, the wound will gape to a greater or lesser degree. Langer (1861, 1862) was the first to use the amount of retraction of the wound edges as an indication of the degree of tension naturally occurring in skin. He found that there were directional variations and that the lines of tension coincided with his cleavage lines.

Skin flaps also retract. In the pig, flaps cut longitudinally, i.e. parallel to the long axis of the animal, retract in length and to a much lesser extent in breadth; flaps cut vertically, i.e. at right-angles to the long axis retract most markedly across their width and not at all in length. Some may indeed elongate showing that skin is not always under tension but may exist naturally in compression (Fig. 1).

When a retracted flap is sutured to the original defect or to a new defect of the same size, it is subjected to the tensions normally existing in the skin.

Fig. 1. On the left, a longitudinal flap; on the right, a vertical flap. The axis of the longitudinal flap runs parallel to Langer's lines and retracts along its length. The vertical flap retracts along its breadth and may actually become longer.

Address for reprints: Professor P. M. Stell, Ch.M., F.R.C.S., Royal Liverpool Hospital, Prescot Street, P.O. Box 147, Liverpool L69 3BX.

The tension may in fact be higher than this because of oedema in the flap resulting from its elevation.

There is some controversy in the literature whether retraction should be allowed for in designing skin flaps. Barron and Emmett (1965) state that the flap should be the same size and shape as the defect while Cannon *et al.* (1947), Coakley *et al.* (1950), Blocker and Mithoefer (1950) and Crawford (1965) all believed that the flap should be cut one-quarter to one-third longer than the defect so that it could be sutured in place in its relaxed retracted state.

It therefore seemed worthwhile to take the sutured retracted flap as the standard and study variations in viability with flaps under normal tension, i.e. flaps sutured back into the original defect, flaps under increased tension and flaps under the maximum applicable tension. First, however, it was necessary to study the extensibility of the pig skin over the trunk which was being used for the flaps.

Skin extensibility. Twenty skin flaps were studied on the abdominal wall of 2 pigs of a mixed Large White Landrace cross in the 35 to 40 kg range. Under general anaesthesia, flaps 40 × 40 mm were marked out in pairs, one longitudinal and the other vertical. After raising the flaps, their new length, width and thickness were measured. A light bar with 5 hooks was attached to the end of the flap to distribute tension evenly, and the bar was attached by a fine thread over a pulley to a pan. Weights were added to the pan at 10 second intervals, taking care not to release the tension on the flap, and keeping the pulley at the same height throughout in such a way that the flap was just lifted clear of the pig's abdomen (Fig. 2). The length of the flap

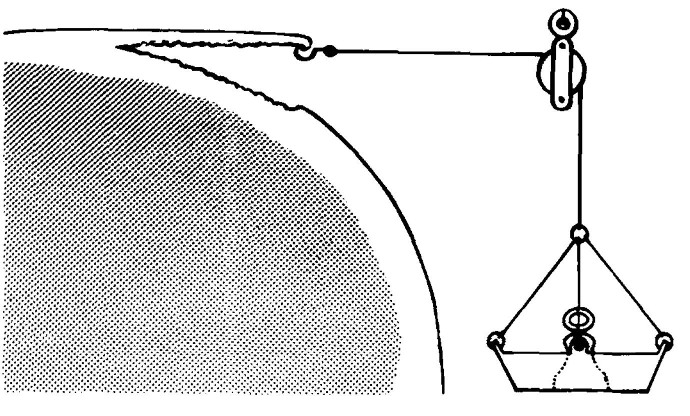

FIG. 2. Outline of the apparatus used to measure extensibility of pig skin in the living animal.

was measured after each addition of a further load, and the length at which the skin flap blanched was noted. The animals were maintained in a standard, neutral, position throughout with their limbs vertical.

The data obtained were analysed statistically by normal theory methods and plotted as shown in Figures 3 and 4. In engineering terms these are "stress/strain" curves. "Stress" on the vertical axis is the load applied to the flap and was measured in grams per square millimetre. "Strain" is a measure

3

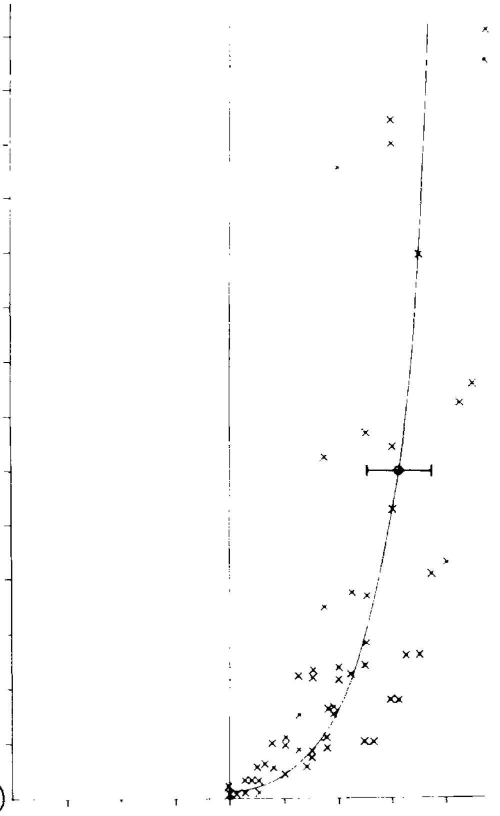

FIG. 3. Stress/Strain curve of a vertical flap. The vertical axis "Stress" is the load applied. "Strain" is a measure of the extension produced. To begin with much extension results from little increase in force. Finally much force is required to produce any extension. This is the phase of "terminal stiffness". The vertical line indicates the original length of the flap and since there was no retraction the curve begins there.

of the extension which occurred related to the original length of the flap. The "original" length was that marked out *before* cutting.

Both curves have the same general shape which is similar to that obtained with human skin (Gibson and Kenedi, 1967). There is an initial portion which represents an increase in length with little increase in load and a terminal part which indicates that further extension can only occur with very large increases in the stretching force. The vertical flaps do not retract in length when cut and can be stretched by about 25 per cent before blanching occurs. Longitudinal flaps retract by about 30 per cent when raised and the load required to return them to their original length usually causes blanching; they cannot be stretched further without very great increase in load. The curves are thus parallel but a significant distance apart.

These directional variations and the overall pattern of extensibility show that in these respects pig skin is similar to human skin (Stark, 1977).

The effect of the tension produced by returning retracted flaps to their original length. Pigs similar to those in the extensibility studies were

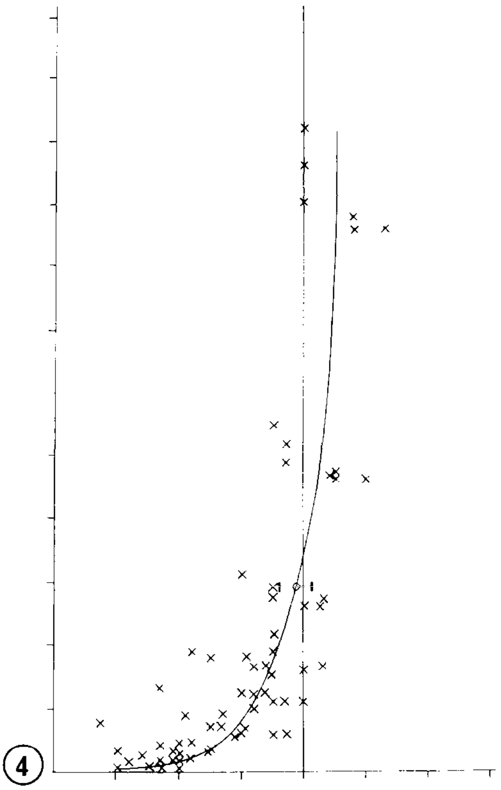

FIG. 4. Stress/Strain curve of a longitudinal flap. Because of the retraction, loading is required to return the flap to its original length. Otherwise the curves are similar and parallel but some distance apart.

used. Three initial experiments showed that a suitable size of longitudinal flap which became necrotic distally was 110 mm long and 50 mm wide based anteriorly. Twenty-one pairs of such flaps were designed on 7 pigs in a similar position to each other on opposite sides of the pig's abdomen; the pig's limbs were again in the neutral, vertical position. The flaps were raised superficial to the panniculus carnosus (i.e. they were random patterned), allowed to retract and the retraction measured. The flap on one side was then returned to its original position while the other was sutured in the position it adopted as a result of retraction.

There was no significant difference in the surviving lengths of each type of flap.

The effect of the tension caused by moderate stretching beyond the original length. Twenty-one pairs of similar longitudinal flaps were raised in 7 pigs. One of each pair was sutured back in place while the other was stretched by lengthening the defect by excising a further 20 mm.

Again there was no significant difference in the surviving lengths in each group.

The effect of applying maximum tension to the flap. Twelve pairs of vertical flaps were studied on 2 pigs. The flaps had a base of 30 mm and a length of 42 mm, which is known from previous data (Stell, 1977) to be the mean surviving length of random flaps with this size of base. Half of the flaps should thus, in theory, undergo some distal necrosis and some should survive completely.

One flap in each pair, determined randomly, was stretched by pulling on it as hard as possible, and the defect was enlarged as much as necessary to accommodate this increased length. The flap was then sutured under this increased tension while the other flap in each pair was sutured in its original position. The mean extension which occurred in the stretched flaps was 56·7 per cent (s.e. 8·6), i.e. they had been stretched well into the phase of "terminal stiffness" (Figs. 3 and 4).

Virtually all of the flaps under maximum tension underwent distal necrosis, although 1 flap survived completely after being stretched more than half its original length. Half of the control flaps survived completely.

The surviving lengths of the flaps stretched to their maximum was greater than the predicted lengths but not significantly so.

The effect of tension applied across a flap. Fifteen pairs of vertical flaps were studied in 2 animals in 3 groups with bases of 5, 10 and 15 mm respectively. The flaps were based opposite each other in pairs, the order of each pair along the abdomen being completely randomised. They were again raised superficial to the panniculus carnosus. One flap in each pair, the side being decided randomly, was sewn back in its original position while the others had the end of the flap only sewn to the edge of the skin defect so that the length remained unaltered; the sides of the flaps were left unsutured.

There was no difference in the surviving lengths of each group.

Discussion

The mechanical characteristics of pig skin are similar to those of human skin and show similar directional variations; the tension along the length of the animal is much greater than at right-angles to it. In man it has been shown that Langer's lines are not only cleavage lines but lines of tension and indicate the direction of minimal extensibility (Gibson *et al.*, 1971). In other words, flaps whose long axis is at right-angles to Langer's lines can probably be stretched to some degree without producing necrosis, while much more care is required with flaps whose long axis is along Langer's lines.

These experiments do not confirm the widely held belief that flaps should be cut bigger than the defect to be covered because a retracted flap returned to its pre-retraction size is subject to tension which may interfere with its viability. Restoring longitudinal flaps to their original size and vertical flaps to their original breadth had no adverse effect.

Excessive force did of course produce additional necrosis but not so much as might have been expected. It should be remembered that skin is, in engineering terms, a "viscoelastic" material. This has 2 related effects. When skin is stretched and the distance held constant, the force required to keep it there gradually decreases; many a flap blue at the end of an operation and pink the next day owes its survival to this phenomenon. The corollary to stress relaxation is "creep"; skin subjected to high loads will "creep", i.e. stretch in the direction of the applied load (Millington *et al.*, 1971). These are factors which are difficult to measure in the living animal or in man but they should be kept in mind although not relied upon to produce miracles.

Summary

When pig skin is progressively extended the graphs obtained are similar to those in man. There are directional variations depending on the orientation of flaps to Langer's lines.

A variety of flaps were subjected to 3 grades of tension: normal, i.e. the flap sutured into its original position; slightly stretched; maximally stretched.

Flaps sutured in their normal position were no different from those sutured in their retracted position.

The surviving length in each group did not differ significantly but flaps under maximal tension were more likely to undergo distal necrosis.

References

Barron, J. N. and Emmett, A. J. J. (1965). Subcutaneous pedicle flaps. *British Journal of Plastic Surgery*, **18,** 51.

Blocker, T. G. and Mithoefer, J. (1950). The pattern flap. *Plastic and Reconstructive Surgery*, **5,** 163.

Cannon, B., Lischer, C. E., Davis, W. B., Chasko, S., Moore, A., Murray, J. E. and McDowell, A. (1947). The use of open jump flaps in lower extremity repairs. *Plastic and Reconstructive Surgery*, **2,** 336.

Coakley, W. A., McCoy, S. M. and Kelleher, J. C. (1950). The use of direct forearm flaps in resurfacing defects of the soft tissues of the lower extremities. *Plastic and Reconstructive Surgery*, **6,** 413.

Crawford, B. S. (1965). The management of tube pedicles. *British Journal of Plastic Surgery*, **18,** 387.

Gibson, T. and Kenedi, R. M. (1967). Biomechanical properties of skin. *Surgical Clinics of North America*, **47,** 279.

Gibson, T., Stark, H. L. and Kenedi, R. M. (1971). The significance of Langer's Lines: in "Transactions of the Fifth International Congress of Plastic and Reconstructive Surgery", edited by Hueston, J. T. Australia: Butterworths.

Langer, K. (1861, 1862). On the anatomy and physiology of the skin. Translated by Gibson, T. (1978). *British Journal of Plastic Surgery*, **31,** 3, 93, 185 and 273.

Millington, P. F., Gibson, T., Evans, J. H. and Barbenel, J. C. (1971). Structural and mechanical aspects of connective tissue, in "Advances in Biomedical Engineering", edited by Kenedi, R. M. London and New York: Academic Press.

Stark, H. L. (1977). Directional variations in the extensibility of human skin. *British Journal of Plastic Surgery*, **30,** 105.

When this contribution from Professor Stell was submitted for publication, I could make neither head nor tail of the original text. The manuscript was sent to several members of the Editorial Committee, none of whom could understand it either. I am, therefore, most grateful to my predecessor, Tom Gibson, for re-writing the text, removing the incomprehensible mathematics and producing this little masterpiece. It is a model of clarity that I hope will be appreciated by our readers.

Michael N. Tempest